# Comparison of different multifunctional landscapes approaches for flood control in developing countries

Comparaison de différentes approches d'espaces pluri-fonctionnels pour la prévention des inondations dans les pays en développement

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## RESUMÉ

Les problèmes urbains de drainage affectent la plupart des villes du monde. Dans les pays en développement ces problèmes sont habituellement plus mauvais que dans autres régions. Un concept alternatif pour réduire le risque d'inondation est l'utilisation d'espaces pluri-fonctionnels. Cet article présente deux approches différentes d'espaces pluri-fonctionnels développées pour l'état de Rio de Janeiro au Brésil. Les résultats et la discussion présentent l'exposition que cette technique atteindre son but. Encore ils montrent que des architectes, planificateurs urbains et les ingénieurs doivent coopérer afin de développer les projets qui accomplis non seulement des objectifs en termes de réduction d'inondation mais également au sujet des besoins des communautés locales.

## ABSTRACT

Urban drainage problems are serious concerns that affect most cities around the world. In developing countries these issues are usually worse than in other regions. An alternative concept to reduce flood hazard is the use of multifunctional landscapes. This paper presents two different multifunctional landscapes case studies developed for Rio de Janeiro State, in Brazil. The results and discussion presented show that this technique is suitable to reach the desired goal. Moreover, it demonstrates that architects, urban planners and engineers need to cooperate in order to develop projects that not only fulfil its objectives in terms of flood levels reduction but also consider other needs of local communities.

## KEYWORDS

Developing countries, Developing countries, Multifunctional landscapes

## 1. INTRODUCTION

Flood control is one of the major issues with which urban planners must deal nowadays. According to Freeman (1999), 60% of human life losses and 30% of economic losses caused by natural disasters are due to floods. In developing countries this problem is often more critical than in other regions. While developed countries face challenges related to an integrated control of water quantity and quality, most of the developing countries are still solving quantity problems.

The concepts applied to the design of stormwater control interventions have changed a lot in the past decades. In general, most of the solutions developed in the past were based on the enlargement of the drainage network in order to suite channels and pipes to convey stormwater flows that grow as the urbanization process takes place. Modern concepts try to focus on the reduction of urbanization hydrological impacts by using infiltration and storage measures (Coffman, Cheng, Weinstein and Clar, 1998). In some highly populated urban regions, the lack of free spaces to settle flood control facilities and the high costs required to provide the removal and reallocation of the population living in high flood risk areas restricts the range of solutions available. In this context, one interesting possibility is the use of multifunctional landscapes designed with additional hydraulic and hydrologic function. This paper presents and compares two different case studies developed in Brazil in which these techniques are being or could potentially be applied.

## 2. URBAN FLOOD PROBLEMS IN DEVELOPING COUNTRIES

The design of urban drainage measures is a process that must consider some local aspects, making each solution unique. Therefore, the pure replication of successful experiences can most often lead to non-effective solutions and unnecessary expenditure of money. The reality of developing countries is much different from the one observed in developed regions. In this way, understanding urban trends in terms of growth and changes of patterns of land use in developing countries is very important in order to support the definition of urban plans and flood control strategies (Murakami, Zain, Takeuchi, Tsunekawa and Yokota, 2005), which should also consider social, cultural and environmental aspects (Keizrul, Mokhtar, Spry and Phillips, 2001; Wondimu and Alfakih, 2001). Some urbanization and urban floods issues common to developing countries are listed below:

- extremely high population growth over a small period of time ;
- unplanned urban growth and patterns ;
- deficiency in spatial cover of drainage, water supply, sewerage, and wastewater treatment infrastructure ;
- lack of appropriate removal and disposal of solid wastes ;
- lack of investment capability ;
- great needs in terms of definition of plans and guidelines for urban drainage management and qualification of local authorities staff ;
- conflicts in terms of definition of responsibilities of governmental authorities ;
- habitational policies that are usually unable to prevent irregular settlements ;
- legal and illegal occupation of flood risky areas ;
- communities with large number of occurrences of water-related diseases ;
- large number of poor slums, where most of the problems are located ;
- lack of education and awareness of population, who sometimes cause damages to flood control structures and dispose garbage over river banks ;

- difficulty to diagnose problems and to settle solutions due to public security problems (e.g., poor areas controlled by drug dealing organizations or gangs).

## 3. COMPARISON OF DIFFERENT MULTIFUNCTIONAL LANDSCAPE APPROACHES

Several definitions of multifunctional landscapes have been presented by different authors. The basic idea is that a given area can fulfil different functions and objectives regarding ecological, economical, cultural, historical and aesthetical concerns (Brandt, Tress and Tress, 2000). The application of this technique to developing countries is feasible but must consider particular aspects related to local communities and other stakeholders in order to be successful. The following case studies present two multifunctional landscape approaches, with stormwater control functions, developed for Rio de Janeiro State (RJ), in Brazil.

### 3.1. Adding stormwater control features to urban revitalising programs in Rio de Janeiro municipality

The municipality of Rio de Janeiro presents a highly urbanised environment, with many irregular occupations in slope and natural flood areas. Floods caused by intense rainfall during the summer are one of the major concerns of the population. In this town, the City Hall has been developing, since 1993, a revitalising program of the urban space, acting on public squares, re-defining streets alignment, creating new parking areas and bikeways, recovering sidewalks, and acting on the major drainage net. This program is known as “Rio-Cidade”. The main focus of the drainage actions already held by this program consisted in pipes and channel enlargements. These measures, most of the time, transfer the flooding problem to areas located downstream. Following an analysis of the implemented projects, some alternative actions were proposed, in the context of multifunctional landscapes, avoiding actions on the existing drainage net and using distributed control of runoff flows. The use of distributed storage and on-site control techniques are usually cheaper than traditional approaches of enlargement of the drainage net (Andoh and Declerck, 1999). In this way, developing countries, where significant investment capability restrictions is a reality, should make an effort to use these kind of solutions more frequently.

One of the proposed actions consists in the possibility of re-urbanisation of public squares to work as temporary detention reservoirs. In urban regions, the lack of free spaces to use as stormwater control facilities is often critical. On site detention measures could surely help to solve the problem, but it depends basically on the acceptance of stakeholders (who usually must assume the cost of construction, operation and maintenance of the facilities) and, in developing countries, government authorities can hardly certify that these measures are operating properly or even if they were set (Mascarenhas, Miguez, Magalhães and Prodanoff, 2005). In this way, the use of public spaces to work as stormwater control measures can lead to a minor risk of failure of the system.

The use of public squares as flood control measures faces two major challenges: a) convince local community and stakeholders of the importance of this measure and develop public acceptance - this action is extremely important and a problem that occasionally happens is that sometimes the community living close to the square that is going to be adapted doesn’t suffer with flooding (this is more typically found in upstream reaches), reducing local acceptance of this kind of measure; b) develop strategies to prevent frequent flooding of the storage chambers during more frequent rainfall events and to clean the place right after the end of an intense storm event. The reason for this is to allow the regular use of the square most of the time, using this space for flood control only once in a while, and preventing the spread of water-

related diseases, as stormwater quality is critical, with presence of sewer and consequently pathogen organisms.

As an illustration of the developed discussion, figure 1 shows a profile view of the project for Edmundo Rego square, in the Grajau district, proposed by COPPE (2004) with an alternative conception (layout), lowered at different levels, for acting as a temporary detention storage pond (total volume of 4.500 $m^3$). Figure 2 shows inflow and outflow hydrographs (20-years return period) for this square simulated with a hydrological and hydrodynamic cell model (Mascarenhas and Miguez, 2002). Some aspects of this project that deserve to be highlighted are: a) a stormwater gallery was diverted to pass below the square; b) a hydraulic structure was designed to prevent flooding of the storage chambers for floods up to 1-year return period; c) the discharge of the pond occurs only by gravity; d) this stormwater control facility does not need operation, although it is required to clean the square after flooding.

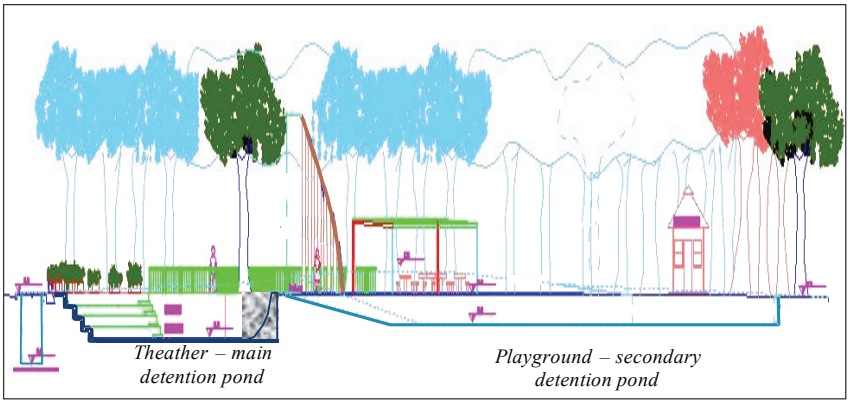


Figure 1. Profile view of the new arrange proposed for Edmundo Rego Square.

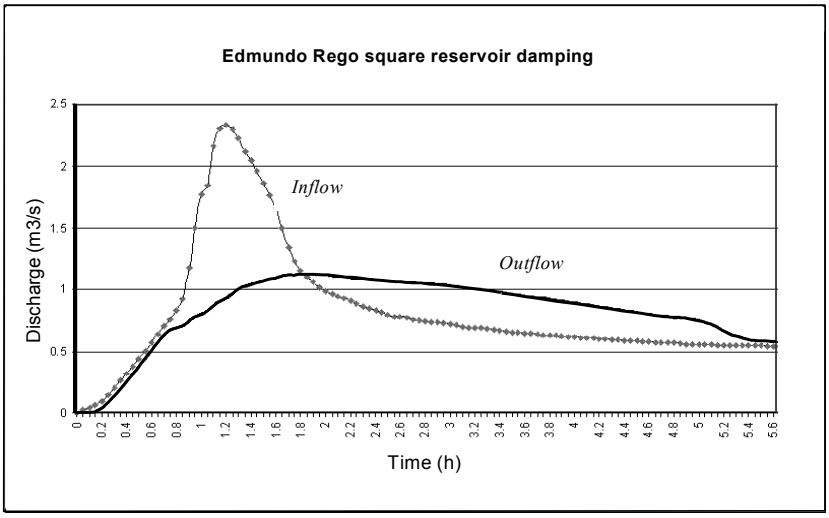


Figure 2. Flood dumping result for Edmundo Rego Square.

Mascarenhas, Miguez and Magalhães (2005) presented results showing that a combination of storage facilities in 12 squares, plus 3 reservoirs in upstream reaches of the formers of the main river of the basin and a set of on-site detention measures could eliminate the 10-years return period floods at the most critical reach of Joana catchment (where it is located Edmundo Rego square), in Rio de Janeiro.

The project proposed for Edmundo Rego Square has not yet been executed. However, a similar proposal has been constructed by the water department of Rio de Janeiro municipality (Rio-Águas) in a public park (Parque Urbano Pinto Teles). The region used to suffer with frequent floods and the area where the park is located had no previous occupation. After the construction of this park with stormwater control features, the frequency of flood in the region has decreased significantly, although the absence of hydrological monitoring makes it impossible to determine precisely this reduction. Nowadays, several activities integrated with local community, such as public fairs and shows, take place at this park.

Some other flood control measures that could be adopted by “Rio-Cidade” Program, such as the use of seeping pavement on sidewalks, bioretention strips close to parking areas, rain gardens, reforesting of hills, were proposed and evaluated by Mascarenhas, Miguez and Magalhães (2005) and Miguez et al. (2005).

Another important urban program in Rio de Janeiro is the “Favela-Bairro”. This program deals with rehabilitation and development of basic urban infrastructure for slum areas. Most of these slums consist in extremely impervious areas located at steep slopes, where there used to be forests (atlantic jungle vegetation). The hydrological impact caused by this change in the occupation of hill areas in Rio is significant (Magalhães, Miguez and Mascarenhas, 2003). A concern that arises when a close look is set on the actions carried out by the “Favela-Bairro” Program is that the imperviousness rate of these communities is increasing considerably. Miguez et al. (2005) proposed some measures that could be adapted to this program in order to reduce the hydrological impacts of these areas through storage and infiltration techniques.

### 3.2. Use of soccer fields as complementary areas of a temporary storage pond in a poor community

This second case study refers to a region of RJ known as Baixada Fluminense, located at the metropolitan region of Rio de Janeiro and occupied mostly by low-income families. This region is also characterised by low level lands naturally subject to floods caused by Iguaçu and Sarapuí rivers. Dikes have been built to prevent the flooding of this region, and as a consequence, polder areas were created. The typical arrange of these polders consists of a stormwater temporary storage pond which receives the major drainage channels and is connected to Iguaçu or Sarapuí rivers through flap gates. The use of flap gates to allow discharge of these polders has the advantage that this kind of structure is passive, robust and requires no operation. The disadvantage is that the discharge can only take place during low tides and these periods can sometimes be delayed due to the routing of floods in the Iguaçu and Sarupuí rivers and adverse climatic conditions. Pump stations could overcome these limitations, but the use of this kind of solution in such case can be considered inappropriate due to the lack of security of the facilities (electric cables and pumps could be robbed and it is often necessary to ask local drug dealers for permission to visit the area) and high operation and maintenance costs. As a result, in order to prevent the water from rising up to a certain level that could cause uncontrolled flood of the surrounding area and consequent failure of other elements of the drainage system, a greater temporary storage volume is required.

Polder Alberto de Oliveira, which receives drainage of part of São João do Meriti and Duque de Caxias municipalities (RJ), can be taken as an example of what is occurring with other polder areas in the Baixada Fluminense region. Almost 80% of its original area designed to work as stormwater temporary storage pond has been occupied by regular and irregular buildings (COPPE, 2003). Visiting this community, it can be observed that one of the measures developed by local population, in order to prevent flood losses, was building their homes over 1.0 to 1.5 meter tall pillars. Urbanization of the catchment also aggravates the problem, as the runoff production got higher than that estimated by the time the original pond was designed. These two factors caused the flood risk of the region to rise considerably. Recent storms and the extension of flooding areas caused a lot of public pressure over the municipalities and state governments. The response of the authorities was the creation of a program to reduce the flood risk in this area. So forth, studies have been carried out in order to determine which interventions are needed to maintain the water inside the pond, considering a maximum water level that could cause no flood hazard to the surrounding community. A hydrodynamic and hydrological cell model (Mascarenhas & Miguez, 2002) was used to simulate the flood at the polder area and at the Sarapuí river. A 20-years return period (RP) storm was set for the polder area and a 10-year RP storm was used for the Sarapuí river basin.

The results of the mathematical simulation showed that three possibilities could reduce water level in the storage pond area to the desirable level (COPPE, 2003): a) double the number of flap gates; b) set a $8m^3/s$ pump station close to the remaining storage area; c) reallocate part of the population that occupies the original temporary pond area. Due to the already mentioned problems concerning pump facilities this alternative has been abandoned. One demand of state authorities was the reduction of the number of families in need of reallocation. The final scenery proposed considered an increase of the number of flap gates (60% more flow capacity) and the lowering of the ground level of two areas close to the remaining storage pond. Few families occupy one of these areas and several soccer fields occupy the other. Figure 3 shows the cell division of the region and these areas.

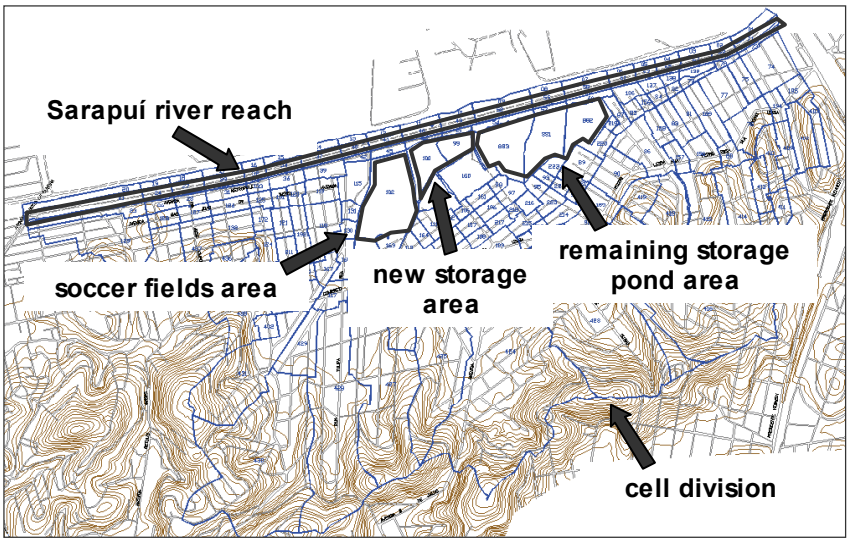


Figure 3. Cell division of the region of interest and new areas added to the remaining pond.

An interesting aspect about the behaviour of local communities in Brazil is that it is very hard to prevent the occupation of free spaces close to poor communities, but soccer field areas are almost always respected, as there is a public perception that these areas serve as leisure and sport facilities for the community. Part of the strategy was setting a multifunctional landscape at the soccer fields' area, so that it could assume a new function, flood control. The proposal was lowering this area to a ground level higher than the other new storage area which is being added to the remaining pond, so that this complementary storage volume gets used only in case of more intense storms, allowing its sportive function at most of the time. The set of measures presented in the final scenery are currently under construction.

### 3.3. Other possibilities of use of multifunctional landscapes

There are many other possibilities of use of multifunctional landscape in urban environments. One of them is the use of greenways, which can often assume a large number of functions, including ecological or hydrological features (Ahern, 1995; Seams, 1995). This kind of measure could be applied to riparian areas occupied by irregular settlements whenever the removal of this population is needed. The establishment of greenways can even cause the price of properties in the surrounding community to rise due to the proximity of natural or aesthetical landscape among other expected benefits (Luttik, 2000).

Another possibility of multifunctional landscape is the use of rooftop gardens. This kind of structure also allows the development of several activities and functions. Thinking on rooftops with a stormwater control concern, it can be noticed that these areas are very impervious surfaces in which source control techniques could possibly be applied. In this way, the construction of rooftop gardens may reduce this problem. In Singapore, this kind of measure has shown good results (Yuen and Hien, 2005) and the use and the perception of relevance of these spaces by the population is growing with time.

## 4. CONCLUDING REMARKS

Several regions located in developing countries suffer with serious flooding problems. Traditional engineering solutions frequently show the trend to transfer problems to downstream reaches (e.g., channel enlargement measures). A multidisciplinary approach can be applied in order to develop new control measures acting over the urban landscape. In this way, typical urban structures may incorporate hydrologic and hydraulic functions, as complementary features, in order to allow a systemic action over the basin, rescuing when possible flow patterns close to the natural ones. These alternative proposals, as illustrated in the presented case studies of this paper, have potential to generate very positive results. In developing countries, this approach can also meet other important goals, such as the revitalisation of irregularly occupied areas. This approach can be an important ally in the search for an equilibrate, harmonic and sustainable environment in a long term.

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